



**ECONOMIC RESEARCH**  
FEDERAL RESERVE BANK OF ST. LOUIS  
WORKING PAPER SERIES

## Gold, Fiat Money and Price Stability

<b>Authors</b>	Michael D. Bordo, Robert D. Dittmar, and William T. Gavin
<b>Working Paper Number</b>	2003-014D
<b>Revision Date</b>	May 2007
<b>Citable Link</b>	<a href="https://doi.org/10.20955/wp.2003.014">https://doi.org/10.20955/wp.2003.014</a>
<b>Suggested Citation</b>	Bordo, M.D., Dittmar, R.D., Gavin, W.T., 2003; Gold, Fiat Money and Price Stability, Federal Reserve Bank of St. Louis Working Paper 2003-014. URL <a href="https://doi.org/10.20955/wp.2003.014">https://doi.org/10.20955/wp.2003.014</a>

<b>Published In</b>	B E Journal of Macroeconomics
<b>Publisher Link</b>	<a href="https://doi.org/10.2139/ssrn.896282">https://doi.org/10.2139/ssrn.896282</a>

Federal Reserve Bank of St. Louis, Research Division, P.O. Box 442, St. Louis, MO 63166

The views expressed in this paper are those of the author(s) and do not necessarily reflect the views of the Federal Reserve System, the Board of Governors, or the regional Federal Reserve Banks. Federal Reserve Bank of St. Louis Working Papers are preliminary materials circulated to stimulate discussion and critical comment.

# Gold, Fiat Money and Price Stability

Michael D. Bordo, Robert Dittmar, and William T. Gavin

## Abstract

The classical gold standard has long been associated with long-run price stability. But short-run price variability led critics of the gold standard to propose reforms that look much like modern versions of price path targeting. This paper uses a dynamic stochastic general equilibrium model to examine price dynamics under alternative policy regimes. In the model, a pure inflation target provides more short-run price stability than does the gold standard and, although it introduces a unit root into the price level, it leads to as much long-term price stability as does the gold standard for horizons shorter than 20 years. Relative to these regimes, Fisher's compensated dollar (or pure price path targeting) reduces inflation uncertainty by an order of magnitude at all horizons. A Taylor rule with its relatively large weight on output leads to large uncertainty about inflation at long horizons. This long-run inflation uncertainty can be largely eliminated by introducing an additional response to the deviation of the price level from a desired path.

**KEYWORDS:** Gold standard; compensated dollar; inflation targeting.

**JEL CLASSIFICATION:** E31, E42, E52

Original Date: 9 June 2003, Revised May 2007

Michael D. Bordo  
Professor of Economics  
Rutgers University  
Department of Economics  
75 Hamilton St.  
New Brunswick, NJ 08901  
[bordo@econ.rutgers.edu](mailto:bordo@econ.rutgers.edu)

Robert D. Dittmar  
Director, Risk Analytics  
1601 Market Street  
Philadelphia, PA 19103  
[Robert.Dittmar@radian.biz](mailto:Robert.Dittmar@radian.biz)

William T. Gavin  
Vice President and Economist  
Research Department  
Federal Reserve Bank of St.  
Louis  
P.O. Box 442  
St. Louis, MO 63166  
[gavin@stls.frb.org](mailto:gavin@stls.frb.org)

We thank Kevin Huang, Finn Kydland, Zheng Liu, Jeremy Piger, Robert Rasche, Martin Sola, Mark Wynne, and participants in seminars at the Federal Reserve Bank of St. Louis, the Missouri Economic Conference and the Midwest Macroeconomics Conference for helpful comments. Athena Theodorou provided research assistance.

## I. INTRODUCTION

A commodity money regime such as the classical gold standard has long been associated with long-run price stability. During that era, though, many economists worried about instability associated with the gold standard and proposed fundamental reforms. Fisher (1934) traces the evolution of the idea of a monetary standard based on a price index and describes 28 nineteenth century proposals made by legislators and prominent economists.<sup>1</sup> Perhaps the most well known is the compensated dollar proposal made by Fisher (1913) himself. Since the end of the gold standard, many economists have argued that a fiat money regime based on credible rules for low inflation could do better than commodity money (see, for example, Friedman 1951, 1960). In 1980 that promise was in doubt. High and variable inflation was the number one economic problem facing the major market-type economies. The U.S. gold commission was given a mandate to evaluate a future role for gold in the U.S. monetary system.<sup>2</sup> Since then, however, it appears that central banks have learned how to maintain low inflation in a fiat money system. Many central banks have adopted implicit or explicit inflation targets in this new era.

In this paper we examine the price stabilizing characteristics of various monetary regimes, some with commodity money and some with only fiat paper currency. We demonstrate that pure inflation targeting in a paper money standard can deliver as much price stability as a commodity standard. The high inflation experience in the 1970s reflects central banks' focus on goals such as output stabilization rather than inflation control. We also show that the degree of instability in the price level under either a commodity standard or inflation targeting is still an order of magnitude greater than is possible under Fisher's compensated dollar proposal or a regime that targets a price path or, equivalently, a long-term average inflation rate. It is also shown that a central bank that pays some attention to a path for the price level can also pay attention to the real economy without sacrificing price stability.

We use a dynamic general equilibrium model of a two-sector economy to evaluate the time-series properties of the price level associated with alternative monetary regimes. When we compare inflation data from the gold standard era with modern times we are comparing apples and oranges because the composition of the economy was much different then, as were data collection methods. There

---

<sup>1</sup> Included among them were Stanley Jevons in 1876, Robert Giffen in 1879, Leon Walras in 1885, Alexander Del Mar in 1885, Alfred Marshall in 1887, F.Y. Edgeworth in 1889, and Knut Wicksell in 1898.

<sup>2</sup> See Report to the Congress of the Commission on the Role of Gold in the Domestic and International Monetary Systems, March 1982.

were also very different government programs and regulations affecting the stability of the financial sector and the size of cyclical fluctuations in the two periods. The model allows us to examine the alternative monetary regimes under common (although artificial) economic environments.

Our model is related to the multi-sector real business cycle model in Long and Plosser (1983) and the monetary business cycle model in Dittmar, Gavin, and Kydland (2005). We also draw from Sargent and Wallace (1983), who address fundamental issues about welfare and the evolution of commodity money. They showed conditions under which consumers are unambiguously better off if convertible paper replaces gold coins as the circulating medium of exchange. And they showed that in a world with two capital goods, the one with the lower depreciation rate emerges as commodity money. Although we label that commodity gold in this paper, we adopt a more general parameterization of the commodity, so that it functions as a capital good, a consumption good, and as money. We examine cases with pure commodity money and cases with pure fiat money where the central bank has full credibility for its policies. Therefore, we are not examining a key role of the gold standard as a rule for price stability or a mechanism for commitment (see Bordo and Kydland, 1995).

Next, in Section II, we compare the behavior of the price level in 13 countries under the classical gold standard regime (1880-1913) with behavior under recent fiat money regimes (1968-2001). Section III is a dynamic stochastic general equilibrium model of an economy with alternative monetary arrangements. Section IV includes a brief comparison of the model properties with the cyclical behavior of output and prices in 13 countries that were on the gold standard from 1881 through 1913. In section V, we compare price dynamics under a pure commodity money standard and a regime built on Fisher's compensated dollar proposal. Section VI analyses regimes with paper money and interest rate rules.

## **II. HISTORICAL PERSPECTIVES**

Price stability is a vague term that may be defined on several dimensions. A stable price is not only one in which the price level does not drift away from a constant level, but it is also one in which the expected inflation rate is relatively predictable over all horizons. A price level is less predictable if the shocks to the price level are larger and if they are more persistent. We look at measures of average inflation to judge, ex post, whether a regime has been associated with price stability. We also estimate the persistence in the price level using the size of the largest root. This turns out, for reasons discussed below, not to discriminate very well between the monetary regimes. Therefore we focus on other measures

of dispersion in the expected price level to gauge the effect of the monetary regime on price stability.

The classical gold standard prevailed in all the developed economies in the period from 1880 to 1914. It provided a simple rule for domestic monetary authorities and for the international monetary system. The rule was to maintain the value of national currency in terms of a fixed weight of gold (this price is referred to as the mint price). In the United States, during this period, the mint price was set at \$20.67 per ounce of gold. Under the gold standard, the purchasing power of gold will tend to equal the long-run cost of production.<sup>3</sup> According to Table 3 in Jastram (1977), the purchasing power of gold in the United Kingdom fell about 40 percent during the 240 years from 1560 to 1800. From 1800 to 1900, it rose 94 percent. This is a very small decline in the trend before 1800, but a faster rise afterwards (still less than 1 percent per annum).

Column 2 of Table 1 lists the average inflation rate for the GDP deflator for 13 countries during the gold standard.<sup>4</sup> Inflation averaged about 3 percent annually in Australia and Finland, about 2 percent annually in the Netherlands, and slightly less in the United States. For the other nine countries (Canada, Denmark, France, Germany, Italy, Norway Sweden, Switzerland, and the United Kingdom), the average inflation rate was between plus and minus 1 percent for the period. The range of average inflation over 33 years of these 13 countries on the gold standard is from -0.6 to 3.0 percent with a mean of 0.9 percent. The standard deviation of average inflation across countries is 1.1 percent for this 33-year period.

---

<sup>3</sup> See Barro (1979) and Bordo (1981) for an introduction to the operation of the gold standard in theory and in practice. Goodfriend (1988) and Fujiki (2003) discuss the role of Federal Reserve institutions in operation of the gold standard.

<sup>4</sup> The GDP deflator was not available for Switzerland in the late 1800s, so we use the CPI. The data sources for the gold standard era for all countries except Australia are described in an appendix to Bordo and Jonung (2001). The price data for Australia come from private communication between Michael Bordo and David Pope at the Australian National University.

**Table 1: Measures of Price Stability**  
**Average Inflation and Persistence in the Price level**

	1880 to 1913				1968 to 2001			
	Inflation	$\hat{\rho}^{MU}$	$\hat{\rho}^{95}$	SEE	Inflation	$\hat{\rho}^{MU}$	$\hat{\rho}^{95}$	SEE
Australia	2.9	1.07	1.14	5.27	5.7	1.09	1.15	1.79
Canada	0.8	1.08	1.15	3.78	4.6	1.09	1.16	1.41
Denmark	-0.3	0.99	1.12	2.71	5.8	1.05	1.13	2.41
Finland	3.0	0.75	1.10	2.49	6.6	1.08	1.14	1.91
France	-0.1	1.00	1.12	4.51	5.4	1.08	1.14	1.28
Germany	0.6	1.06	1.12	3.05	3.8	1.06	1.13	2.08
Italy	0.6	1.07	1.14	3.05	8.2	1.07	1.14	2.17
Netherlands	2.0	0.53	1.07	3.5	4.2	0.67	1.09	1.00
Norway	0.7	1.06	1.13	2.51	4.8	1.07	1.14	3.50
Sweden	0.3	0.57	1.08	2.47	6.1	1.09	1.16	1.69
Switzerland	-0.6	0.55	1.07	4.68	3.8	1.07	1.14	1.48
UK	0.4	0.71	1.09	2.86	6.7	0.53	1.07	1.47
US	1.6	1.07	1.14	5.85	4.0	1.08	1.14	1.01
Average	0.9	0.89		3.59	5.3	1.00		1.78

Note: The price level is defined as the logarithm of the GDP deflator.  $\hat{\rho}^{MU}$  is the median unbiased estimator.  $\hat{\rho}^{95}$  is the upper end of a 90 percent confidence interval. SEE is the standard error of the equation in estimates of equation (1').  $\hat{\rho}^{MU}$  and  $\hat{\rho}^{95}$  are based on tables in Stock (1991) using estimates of equation (1'). Shaded cells indicate that the Dickey-Fuller test rejects the hypothesis that there is a unit root in the logarithm of the price level at the 5 percent critical level.

The classical gold standard ended with World War I. After the war it was reinstated as a gold exchange standard whereby member countries could hold international reserves as gold or in the currencies of the key countries: Britain, France, and the United States. The gold exchange standard was short-lived. Eichengreen (1992) describes the collapse beginning in 1931 in the face of the Great Depression and attributes it to fatal policy mistakes made by the United

States and France. The Bretton Woods System established in 1944 was a weak variant of the gold standard. Under this system, the United States maintained gold convertibility at \$35.00 per ounce while the other members maintained current account convertibility in dollars. Most of the adjustment mechanism of the gold standard was thwarted and monetary policy was only in part constrained by gold. The United States eliminated gold cover for currency issue in 1968 and cut the final link with gold in August 1971, when President Nixon permanently closed the gold window. Although many central banks continue to hold gold assets, no country has had a monetary standard with a link to gold since the 1970s.

Today's economies use fiat money and base their nominal anchor on policy rules such as inflation targeting. It took some time following the collapse of Bretton Woods for central banks to learn how to maintain low inflation and relative price stability. Column 5 in Table 1 reports the average inflation rate (again for 33 years—1968 to 2001) in the GDP deflator for the same 13 countries that had been on the gold standard.<sup>5</sup> The two most successful countries, Germany and Switzerland, had 3.8 percent average annual inflation rates, about a percentage point higher than the highest inflation rates observed during the gold standard era. The worst performance was in Italy where the price level rose by a factor 18 (8.2 percent average annual inflation rate). In the United Kingdom the price level rose by a factor of 11 (6.7 percent inflation average). For the other 8 countries, the price level rose between a factor of 4.2 in the United States (4.0 percent average inflation) and 7.9 in Sweden (6.1 percent average inflation). The average inflation rate was much higher (4.5 percentage points higher) in the modern period, although the standard deviation of inflation rates across countries (1.3 percentage points) was only slightly greater than during the gold standard.

In our model of the gold standard, the price level is stationary. Our prior is that the data should reject a unit root in the price level if the data are generated in an era with a successful gold standard. We define persistence using a median-unbiased estimate of the largest root in the characteristic equation of a univariate autoregressive model:

$$p_t = \alpha_0 + \gamma t + \sum_{i=1}^k \alpha_i p_{t-i} + \varepsilon_t, \quad (1)$$

where  $p$  is the log of the GDP deflator,  $t$  is a time trend,  $k$  is the number of lags of price level in the equation, and  $\varepsilon_t$  is a serially uncorrelated, homoskedastic

---

<sup>5</sup> The modern GDP deflator data are calculated from time series of real and nominal GDP provided by the OECD as of January 2003.

random error term. The largest autoregressive root,  $\rho$ , is defined as the largest root of the characteristic equation  $\lambda^k - \sum_{j=1}^k \alpha_j \lambda^{k-j} = 0$ .

A median-unbiased estimate of the largest root is calculated using the test statistic from the augmented Dickey-Fuller (1981) equation, which is a transformed version of equation (1):

$$p_t = \alpha_0 + \gamma t + \alpha_1 p_{t-1} + \sum_{i=1}^k \omega_i \Delta p_{t-i} + \varepsilon_t, \quad (1')$$

where  $\omega_i = \alpha_i - \alpha_{i-1}$ . A distribution for OLS estimates of the  $t$  statistic, denoted  $\tau_\tau$ , on  $\alpha_1$  is presented in Fuller (1976). We use the Akaike information criterion to choose the lag length,  $k$ . Using Table A1 from Stock (1991), information about  $\tau_\tau$  can be used to form a median-unbiased estimate of the largest root,  $\rho^{MU}$ , for each price series. We also present the 95th percentile value for this estimate,  $\rho^{95}$ , which is the upper limit of a 90 percent confidence interval.

Columns 3 and 4 report  $\rho^{MU}$  and  $\rho^{95}$  for the gold standard era. We found that the average lag chosen was two years, although the mode was only one. The median unbiased estimates of the largest root ranged from 0.53 in the Netherlands to 1.08 in Canada. We never reject the null hypothesis of a unit root at the 5 percent critical level (a one-sided test;  $\rho^{95} > 1$  in every case).

Higher inflation during the fiat money era is also matched by higher estimates of persistence. The last four columns of Table 1 report the summary statistics for the modern period. The average lag length is 2.9 for the 13 countries. The median-unbiased estimates of the largest root range from 0.53 in the United Kingdom to 1.09 in Australia, Canada, and Sweden. The average  $\rho^{MU}$  for the period was 1.00. Not surprisingly, we find that  $\rho^{95}$  is greater than unity for all the countries.

We were surprised to see that this measure of price stability did not distinguish between the gold standard and the recent period of relatively high inflation. The problem arises because the price level in both periods reflects persistence coming from real shocks. In our models, when one calibrates the autocorrelation in the technology shocks to match the properties of output, the persistent real shock induces a near unit root in the price level. With these persistent shocks to output, it is impossible to distinguish between a unit root and a near unit root in the price level in periods as short as 33 years. This is also true for inflation under inflation targeting regimes. Therefore we rely on simulations of inflation over long horizons to gauge whether one regime results in more or less price stability than another.



Another dimension of price stability is the variability of innovations to the time series. Column 5 and 9 in Table 1 report the standard error of the estimate (SEE) of the Dickey-Fuller equation as a measure of the short-run predictive uncertainty. During the gold standard era, the average annual SEE was 3.6 percent. This relatively high short-run uncertainty about the price level was a factor leading Irving Fisher and others to advocate monetary reform.

In the recent period the average annual SEE was just half as large at 1.8 percent. As did Klein (1975), we find that although the average inflation rate was higher during the fiat standard, the short-run predictive uncertainty was lower. Meltzer and Robinson (1989) argue some of the high volatility in the earlier period is due to the composition of output and the poorer quality of measurement.

### III. COMMODITY MONEY IN A TWO-SECTOR MODEL

We begin by describing the model with pure commodity money. Later, we add paper money to examine more realistic versions of the gold standard and to compare the gold standard with an economy with fiat money and a target for the inflation rate or a price path. The model has two goods, a commodity that is called gold and a composite good that includes everything but gold. The production sectors for these two goods are embedded in a neoclassical growth model. There are separate shocks to production technology in each sector, but no aggregate shock. Households consume both goods and firms use both as capital. Consumers hold money balances to reduce the time spent shopping. Several monetary regimes are considered, some with gold coins and some with paper money. In all cases, we assume perfect credibility for the government's monetary policy.

This is a closed economy model. Capital can be shifted between sectors with no resource cost so that gold production can respond rapidly to changes in relative prices. Thus, the fluctuations in domestic production play a role similar to international gold flows in an open economy model.

#### The Economy

To simplify the discussion (and because none of our results depend on having an exogenous growth trend), we describe the model without growth. Many identical households inhabit the model economy. Each household maximizes expected lifetime utility,

$$E_0 \left[ \sum_{t=0}^{\infty} \beta^t u(c_{1,t}, c_{2,t}, \ell_t) \right], \quad (2)$$

where  $c_1$  is nonmonetary gold,  $c_2$  is a composite good that includes everything else,  $0 < \beta < 1$  is a discount factor, and  $\ell$  is leisure time. The functional form of the current-period utility function is

$$u(c_{1,t}, c_{2,t}, \ell_t) = \frac{1}{1-\gamma} \left[ c_{1,t}^{\mu_1} c_{2,t}^{\mu_2} \ell_t^{1-\mu_1-\mu_2} \right]^{1-\gamma}, \quad (3)$$

where  $0 < \mu_1, \mu_2 < 1$ ,  $0 < \mu_1 + \mu_2 < 1$ , and  $\gamma > 0$  but different from 1.

In each period, the infinitely lived representative consumer decides how to allocate time between work, leisure, and time spent shopping for consumption goods. Larger money balances brought into the period decrease shopping time and increase the amount of time that can be allocated to work and leisure. At the end of the period, households decide how much money to carry into the next period. In the case of commodity money, they decide how much gold to convert into coin (or how many coins to melt).

Household time spent on transactions-related activities in period  $t$  is given by

$$f(\chi_t) = \omega_0 - \Omega \chi_t^\omega. \quad (4)$$

Real balances,  $\chi_t$ , are defined per unit of consumption equal to  $m_t / \sum_{i=1}^2 p_{i,t} c_{i,t}$ ,

where  $m_t$  is the nominal stock of money,  $p_{i,t}$  is the price of good  $i$ , and  $\Omega$  is the level of payments technology, which is assumed to be constant. The price of gold,  $p_{1,t}$ , is the numeraire, set equal to 1 in the first version of our model. By restricting  $\Omega$  and  $\omega$  to have the same sign and  $\omega < 1$ , the amount of time saved increases as a function of real money holdings in relation to consumption expenditures, but at a decreasing rate. The budget constraint on time is given by

$$\ell_t + \sum_{i=1}^2 h_{i,t} + \omega_0 - \Omega \chi_t^\omega = 1, \quad (5)$$

where  $h_{i,t}$  is time spent in production of good  $i$ .

Sector output,  $Y_{i,t}$ , is produced using labor and capital inputs:

$$Y_{i,t} = z_{i,t} H_{i,t}^{b_i} \prod_{j=1}^2 K_{i,j,t}^{a_{i,j}}, \quad (6)$$

where  $z_{i,t}$  is the level of technology that is subject to transitory shocks and

$b_i + \sum_{j=1}^2 a_{i,j} = 1$ . Both goods are used as capital in both sectors. Competitive factor

markets imply that in equilibrium each factor receives its marginal product. A law of motion analogous to that for individual capital describes the aggregate quantity of capital. The distinction between individual and aggregate variables is

represented here by lowercase and uppercase letters, respectively. The technology changes over time according to

$$\ln(z_{i,t+1}) = \rho_i \ln(z_{i,t}) + \varepsilon_{i,t+1}^z, \quad (7)$$

where  $0 \leq \rho_i < 1$  and the innovation  $\varepsilon_{i,t+1}^z \sim N(0, \sigma_i^2)$ . The steady-state level of technology is chosen to normalize output in each sector to 1.

The budget constraint for the typical individual is

$$\begin{aligned} \sum_{i=1}^2 p_{i,t} c_{i,t} + \sum_{i=1}^2 \sum_{j=1}^2 p_{i,t} k_{j,i,t+1} + b_{t+1} + m_{t+1} = \\ \sum_{i=1}^2 p_{i,t} z_{i,t} h_{i,t}^{b_i} \prod_{j=1}^2 k_{i,j,t}^{a_{i,j}} + \sum_{i=1}^2 \sum_{j=1}^2 p_{i,t} (1 - \delta_{j,i}) k_{j,i,t} + (1 + R_t) b_t + m_t. \end{aligned} \quad (8)$$

On the left-hand side, the total of household consumption in period  $t$  plus assets carried into period  $t+1$  (capital, net bonds, and money balances) are equal to output produced in period  $t$  plus assets brought into period  $t$  (capital, net bonds, and money balances) minus depreciated capital plus interest on net bonds.

### Competitive Equilibrium

A competitive equilibrium is achieved when the representative household and firm solves its optimization problem and all markets clear. The agent's decisions can be reduced to the choice of labor hours,  $h_{i,t}$ , next period's capital stock,  $k_{i,j,t+1}$ , next period's money balances,  $m_{t+1}$ , and net nominal borrowing,  $b_{t+1}$ . When these choices are subtracted from the agent's nominal income in the period, what is left will be split across consumption to satisfy the first-order conditions for consumption:

$$\frac{\frac{\partial u}{\partial c_j}(\bullet_t)}{\frac{\partial u}{\partial c_i}(\bullet_t)} = \frac{p_{j,t}}{p_{i,t}}. \quad (9)$$

The ratios of the marginal utilities of each type of consumption are equated to their relative prices in each period.

To simplify the agent's first-order conditions, we define

$$\kappa_{i,t} = \frac{1}{p_{i,t}} \frac{\partial u}{\partial c_i}(\bullet_t) + f_1(\chi_t) \frac{\chi_t^2}{m_t} \frac{\partial u}{\partial \ell}(\bullet_t). \quad (10)$$

This is an augmented marginal utility of consumption that takes into account the direct impact of consumption on utility and the indirect impact that consumption has on leisure through its effect on shopping time. Equating these augmented marginal utilities across consumption goods gives us the intra-temporal first-order

condition discussed above. Since these are equal across all forms of consumption, we can more simply express first-order conditions in terms of  $\kappa_t = \kappa_{1,t}$ . We also note that, since individual output production functions have the form

$$y_{i,t} = z_{i,t} h_{i,t}^{b_i} \prod_{j=1}^2 k_{i,j,t}^{a_{i,j}}, \quad (11)$$

we can write the marginal product of the various types of capital as  $a_{i,j} \frac{y_{i,t}}{k_{i,j,t}}$  and of various types of labor as  $b_i \frac{y_{i,t}}{h_{i,t}}$ . These conventions allow us to write the agent's first-order conditions taken with respect to labor as

$$\frac{\frac{\partial u}{\partial \ell}(\bullet_t)}{\kappa_{i,t}} = p_{i,t} b_i \frac{y_{i,t}}{h_{i,t}}. \quad (12)$$

This is similar to the usual condition that sets the ratio of the marginal utility of leisure to the marginal utility of consumption equal to the wage rate. The first-order conditions taken with respect to the various kinds of capital take the form

$$E_t \left[ \left( \frac{p_{i,t+1}}{p_{j,t}} a_{i,j} \frac{y_{i,t+1}}{k_{i,j,t+1}} + \frac{p_{j,t+1}}{p_{j,t}} (1 - \delta_{i,j}) \right) \frac{\kappa_{t+1}}{\kappa_t} \right] = \frac{1}{\beta}. \quad (13)$$

The term in parentheses above represents nominal return to the various types of capital. The agent chooses capital levels to equate their expected nominal returns. The first-order condition for nominal lending or borrowing takes the form

$$E_t \left( \frac{(1 + R_{t+1}) \kappa_{t+1}}{\kappa_t} \right) = \frac{1}{\beta}. \quad (14)$$

The first-order condition for next period's money balances is complicated because the choice of money affects the leisure choice in two ways. The amount of money held has a direct effect on shopping time and an indirect one through its effect on consumption. One way of writing the first-order condition for money balances is

$$E_t \left( \frac{\kappa_{t+1} - f_1(\chi_{t+1}) \frac{\chi_{t+1}}{m_{t+1}} \frac{\partial u}{\partial l}(\bullet_{t+1})}{\kappa_t} \right) = \frac{1}{\beta}. \quad (15)$$

If the agent's choices don't affect his shopping time, i.e.,  $f_1(\chi) \equiv 0$ , then the condition above reduces to the standard

$$E_t \left( \frac{p_{1,t}}{p_{1,t+1}} \frac{\frac{\partial u}{\partial c_1}(\bullet_{t+1})}{\frac{\partial u}{\partial c_1}(\bullet_t)} \right) = \frac{1}{\beta}. \quad (16)$$

Money will be held in equilibrium only if its expected return matches the rate of time preference.

The prices for gold and the other good are determined by goods market clearing and the government's monetary rule. In the first two cases, with the gold standard and with Fisher's compensated dollar standard, the rule involves setting the mint price of gold. Households may choose to hold more or less money at the end of the period, when they can take their gold bullion to be coined or their excess coins to be melted. For simplicity, we assume this operation of transferring bullion to coin and back to bullion does not use up real resources.

Under the gold standard, the mint price (currency price of gold) is held constant. Under Fisher's compensated dollar standard, the central bank constructs a price index and manipulates the mint price to fix the price of the non-gold composite good at its steady-state level. For the United States, Fisher recommended using the Bureau of Labor Statistic's wholesale price index, which included over 250 items, but not gold.<sup>6</sup> In this simple case with only gold coins circulating as money, the model is the same as with the gold standard except that the government resets the mint price each period so that the price of the non-gold good is held constant.

### Introducing Fiat Money

With paper money in the economy—whether or not it is backed by gold, the price levels are determined by goods market clearing and the central bank's interest rate rule. The budget constraint, equation (8), is modified by adding transfers,  $v_b$ , to the right-hand side. These transfers can be used to reduce shopping time in period  $t+1$ .<sup>7</sup> We will assume that the central bank has perfect credibility so that people are indifferent between holding gold and government-issued paper claims to gold. Thus, in equilibrium all money balances are paper.

The central bank manipulates transfers to implement an interest rate rule of the type

$$R_{t+1} = \bar{R} + v_\pi (\pi_t - \bar{\pi}) + v_y (y_t - \bar{y}) + v_p (p_t - \bar{p}) + v_{p1} (p_{1t} - \bar{p}_1), \quad (17)$$

---

<sup>6</sup> See Bureau of Labor Statistics (1920, Table 9).

<sup>7</sup> This follows the convention in Kydland (1989) and has the timing of a cash-in-advance model.

where  $\pi_t = p_t - p_{t-1}$  is the aggregate inflation rate,  $y_t$  is the aggregate of production from both sectors,  $p_t$  is the log of the aggregate price level,  $p_{1t}$  is the log of the price of gold, and the bar over a symbol refers to the steady-state value. We use alternative assumptions about policy parameters to model the various policy regimes.

To approximate the dynamics of the model, we use the approach described in King and Watson (1998). In the simple commodity money model we can reduce the agent's decisions to the choice of  $h_{l,t}$ ,  $k_{l,j,t+1}$ , and  $m_{t+1}$ . Consumption ratios are equal to price level ratios, and since net borrowing is zero in equilibrium the choice of  $b_{t+1}$  has no real effects on any of the model's variables in equilibrium.

## Calibration

We calibrate the model to a quarterly period, but then aggregate the model histories to an annual frequency when we compare the model results with historical data. The quarterly specification focuses in on the short-run dynamics and makes it easier to compare this model with the quarterly models that are typically used to study monetary policy issues. The quarterly discount factor,  $\beta$ , is approximately 0.99. The risk-aversion parameter,  $\gamma$ , is set equal to 2. The gold sector is small relative to the non-gold sector. Without loss of generality, we normalize steady-state shopping time to zero and choose time units so that the sum of hours worked in each sector plus leisure is equal to unity in the steady state. Attack and Bateman (1992) report that the standard manufacturing workweek in 1980 was 10 hours per day, six days per week. This level seems much higher than today's, but because there were fewer second workers in each household then, we assume that total labor time,  $h_1 + h_2 = 0.33$ —a workweek for the household overall that is only slightly higher than today. In the steady state, the gold sector uses only 5 percent of available labor, but this sector is slightly more capital intensive than the other sector. The labor share is set to 65 percent in the gold sector and 70 percent in the non-gold sector.

The  $\mu_i$ , the share of gold and non-gold consumption in the utility function, typically are determined from an intratemporal substitution condition such as  $MU_\ell / MU_c = w$ . In the case of a one-sector model, the share of consumption is close to total time spent working. Here the majority of working time is spent in the non-gold sector, so  $\mu_2$  here is quite close to total labor time. Since the intratemporal trade-off between labor and consumption is complicated in our model by the presence of shopping time, the ratio of marginal utilities depends on both wage rates and shopping time. The first-order conditions taken with respect to consumption and labor (equations 9 and 12) are used to calculate the values of

$\mu_i$  implied by the assumptions about hours worked and shopping time; these are  $\mu_1 = 0.015$  and  $\mu_2 = 0.341$ .

The share of gold capital is small relative to other capital. We assume the gold capital share is 0.05 in the gold sector and 0.03 in the goods sector. We use a quarterly depreciation rate of 0.005 for the gold capital and 0.025 for other capital. There are two independent shocks to production technology, one in the gold sector and one in the goods sector. The standard deviation of the technology shock to the non-gold sector is set equal to 1 percent per quarter, larger than recent times, but consistent with output volatility of that era. The autocorrelation parameter on this shock is set to 0.95.

Historically, shocks to the gold sector took many forms. There were new gold mines discovered, new veins of gold in existing mines, and permanent improvements in the technology for extracting gold. In this paper, we consider only a temporary shock to the gold sector. Consider our shock to gold production to be the discovery of a new vein of gold in an existing mine. The newly discovered veins have layers of gold that are increasingly more costly to extract so that the increase in productivity is persistent, but not permanent.

The shock process for gold production is calibrated to capture the effect of uncertainty in production as well as the effect of international gold flows. We calculated the standard deviation of world gold production (for the years 1981 to 1913) to be 7.4 percent annually and of U.S. gold production to be 6.8 percent. When we add net international gold flows in the United States to U.S. gold production (not growth) we find that the variability of the total doubles.<sup>8</sup> Canjels, Prakash-Canjels, and Taylor (2004) find that international gold flows were large and quite responsive to small deviations of the gold price from parity. Although this is only suggestive about the size of the shock to the gold sector, it suggests that the shock to the gold sector is larger than the shock to the non-gold sector. Here we assume that the standard deviation of the gold shock is 2 percent per quarter, double the standard deviation of the shock to the non-gold sector. We also set this autocorrelation parameter equal to 0.95. With this calibration in the model under the gold standard, shocks to the gold sector explain about half of the variability in the inflation rate at all horizons.

In addition to normalizing steady-state output to unity in each sector, we also normalize the price of gold to unity. These choices, coupled with an assumption about the income velocity of money, determine the steady-state money stock. Friedman and Schwartz (1963) report that M2 velocity was about 4 when the United States went on the gold standard in 1879. With this velocity

---

<sup>8</sup> The data used in these calculations can be found in the Statistical Compendium to the Report to the Congress of the Commission on the Role of Gold in the Domestic and International Monetary Systems, March 1982.

assumption and the household's first-order condition for the choice of money holding, the implied value of the scale parameter,  $\Omega$ , is  $-0.0037$ . The shopping time parameter,  $\omega$ , is chosen to be equal to  $-2$ . This value implies steady-state money demand function with an interest rate elasticity of  $-1/3$  and a consumption elasticity of  $2/3$ . The calibration of the parameters of the interest rate rule is discussed in each section as the particular rule is introduced.

#### IV. MODEL VALIDATION

Backus and Kehoe (1992) presented evidence about the cyclical behavior of economies during the gold standard era. They conclude that there is similarity across countries and time in the cyclical patterns for real variables, but the patterns for nominal variables were quite diverse. This result, also documented by Bergman, Bordo, and Jonung (1998), is evident in Table 2 which displays the cyclical variability of output, prices, and inflation for our gold standard model and the 13 countries that were on the gold standard. The last two columns include the covariance of output with prices and inflation.

Table 2. Cyclical Patterns in the Model and in the Gold Standard Countries (1881-1914)

	Standard Deviations (% a.r.)			Correlations	
	$y$	$p$	$\pi$	$\rho(y, p)$	$\rho(y, \pi)$
Gold standard model	2.71	3.04	0.83	-0.65	-0.16
with convertible paper*	2.49	2.91	0.82	-0.52	-0.19
Australia	4.68	4.85	5.67	-0.07	-0.27
Canada	3.60	3.18	3.52	0.23	-0.23
Denmark	2.85	2.83	2.65	-0.50	-0.17
Finland	3.58	2.79	2.91	-0.22	-0.37
France	3.91	3.71	4.64	-0.48	-0.46
Germany	3.08	2.74	3.11	-0.46	-0.17
Italy	2.75	2.51	2.99	0.10	-0.19
Netherlands	6.84	3.75	4.92	-0.75	-0.43
Norway	1.87	3.08	2.54	0.62	0.18
Sweden	2.75	3.26	2.80	-0.07	-0.04
Switzerland	4.70	5.49	4.67	-0.78	-0.31
UK	3.52	2.78	3.04	-0.63	-0.67
US	1.84	4.85	5.61	0.10	0.24

Notes: Output,  $y$ , the price level,  $p$ , and inflation,  $\pi$ , have been detrended using the HP filter.

\*With this calibration, the interest rate rule has a weight of 0.25 on the gold price.



The first two rows display the model results. The technology shock processes were calibrated to approximately match the average output volatility of the gold standard countries. The top row shows the model results where all money is commodity money and the gold price is fixed. The price variability is about the same order of magnitude as output volatility. This is also the case for the gold standard countries. The second row shows results when we add convertible paper money and the central bank uses an interest rate rule to target the price of gold. One puzzling aspect of the gold standard model is that the inflation volatility is much lower than in the data and much lower than price level volatility.

The last two columns describe the cyclical behavior of prices and inflation. Here we can see the problem in trying to match the gold standard facts. The correlations for the price level and output vary between  $-0.78$  and  $0.62$ . The price-output correlation in the gold standard model without convertible paper is  $-0.65$ , but when we add paper currency we get  $0.33$ . The correlations for the inflation rate and output vary between  $-0.67$  in the United Kingdom and  $0.24$  in the United States. In our model, the correlations are negative. They become larger in absolute value with interest rate smoothing.

Overall, our model cannot explain the diversity we see among the gold standard countries. We speculate that building a business cycle model to explain these facts will require extensions involving banking institutions, international trade, and, perhaps, a richer set of shocks. Therefore, we focus on issues involving price dynamics that are mainly a function of the policy process and leave the business cycle issues to future research.

## **V. DYNAMICS OF ADJUSTMENT WITH COMMODITY MONEY**

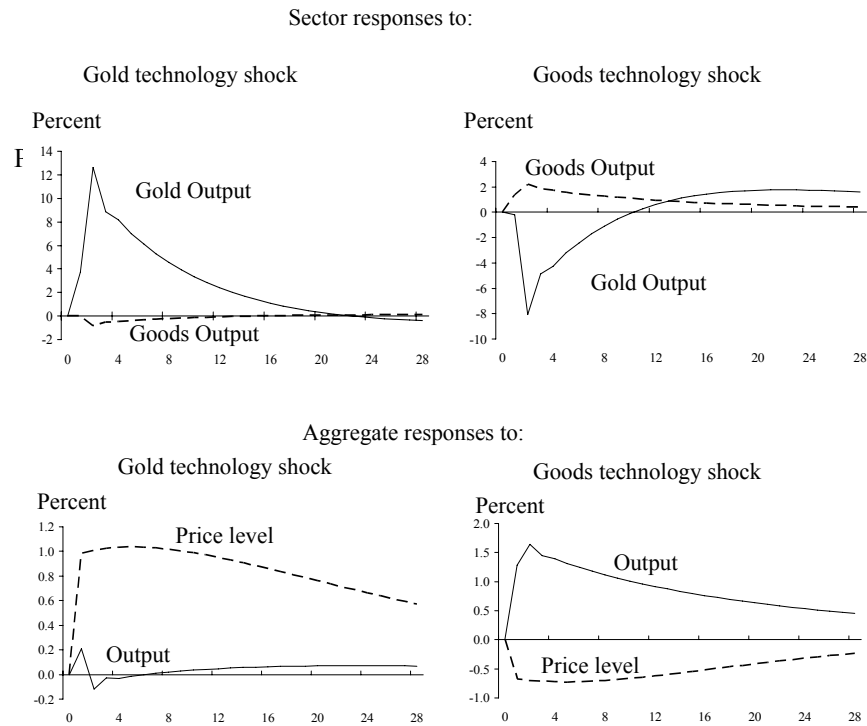
In these first two regimes, all money is in the form of gold coins. Under the gold standard, the government sets the mint price for gold at the steady state level, which, in our model, is normalized to unity. In the case of Fisher's compensated dollar, the government resets the price each period to keep the goods price constant. In both cases, we assume that the government's policy is fully credible and have abstracted from the resource costs that would occur if the government actually implemented either policy.

### **Gold Standard**

Figure 1 shows the response of our gold standard economy to technology shocks. The upper left panel of Figure 1 shows the sector responses to a gold technology shock. Resources move to the gold sector to take advantage of the higher marginal products for capital and labor. By the end of the second period, gold output rises almost 13 percent above the steady state. The output of other goods declines

slightly in the second period as labor and capital of both types move to the gold sector.

Figure 1: The Gold Standard and Technology Shocks



Responses are quarterly. The shocks are one-standard deviation calibrated to 2 percent for the gold technology shock and 1 percent for the non-gold goods technology shock.

Aggregate responses are shown in the bottom left panel. We use the steady-state values as fixed weights in the aggregation. The steady-state output levels are normalized to unity, so the aggregate price level is just the sum of the sector prices. We use the steady-state prices (1.0 for gold and 17.6 for goods) as relative weights in the output index. The price of other goods jumps about 1 percent in the first period, stays at that level for about 2 years, and then gradually falls back to the steady state. Output rises slightly in the first period but quickly reverses.

The upper right panel in Figure 1 shows how the economy responds to a shock to production technology for goods. The economic responses to a goods shock are much larger than those to a gold shock because the goods sector uses 95 percent of market labor time (in the steady state) and represents about 93 percent of expenditures on output. Following this goods technology shock, gold output falls 8 percent below the steady state as resources now move to the goods sector.

Goods output peaks about 2 percent above the steady state in the second quarter following the shock. The lower right panel shows the aggregate response to a goods shock. A 1 percent shock to the goods technology leads to a peak in output in the second period about 1.6 percent above the steady state. The price level falls by 0.7 percent in the first period, stays at that level for about 2 years, and then begins a slow return to the steady state. Notice that although the gold sector is much smaller and a gold shock has only a small effect on real output, it has about the same order of magnitude impact on the aggregate price level as does the goods sector shock.

This result—that output in each of the two sectors moves counter to the other in response to sector shocks—is common in multisector models without adjustment costs (see Murphy, Shleifer, and Vishny, 1989, and Huffman and Wynn, 1999). While this rapid transfer of capital and labor across sectors is not typical of modern business cycles, it is consistent with stories from the period. Certainly, the discovery of gold at Sutter’s mill in California in 1848 led to a rapid deployment of labor and capital to the area.

Next, we use the gold standard model to compute artificial histories to measure percent deviation of inflation from steady state over various horizons. In this log linear model, the percent deviations from steady state are symmetric. In Table 3 we report the standard deviation of the average inflation outcomes in 10,000 experiments at horizons of 1, 5, 15, and 30 years. That is, at each horizon we are measuring the average inflation rate over the interval from the initial period. Row 1 reports the results for the baseline case under the gold standard. The standard deviation for the year ahead is 1.11 percent, more than five times larger than the uncertainty at 30 years (0.19 percent). About half of this volatility is due to the output shock. In row 2, we show that even if there were no technology shocks in the gold sector, we would still have considerable uncertainty in the 1- to 5-year horizon.

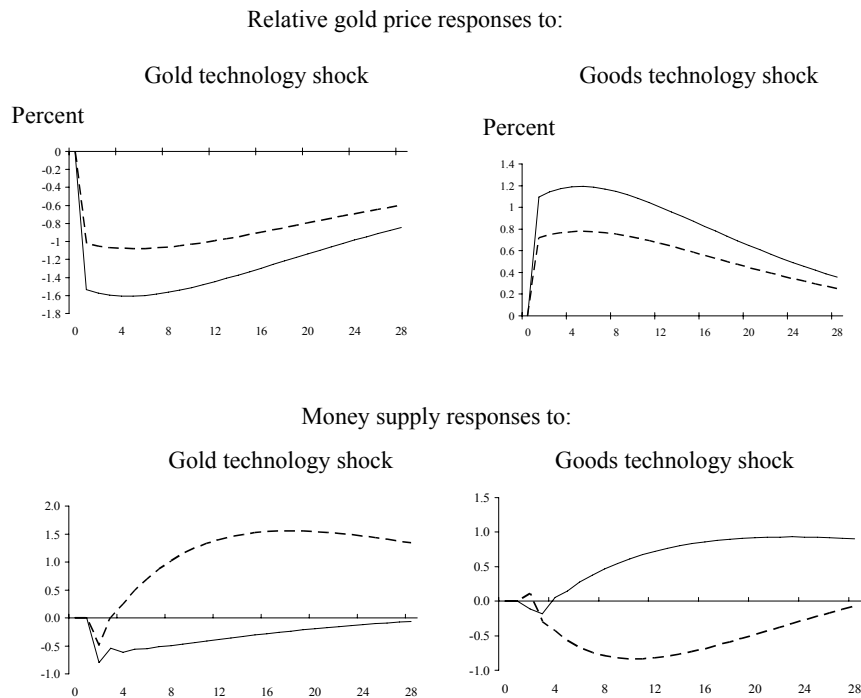
Table 3: Term Structure of Inflation Uncertainty with the Gold Standard and Price Level Rules: Standard Deviation of Average Inflation from Steady State (Percent)

	Horizon	1 year	5 year	15 year	30 year
Gold standard		1.11	0.93	0.37	0.19
Gold standard (no gold shocks)		0.64	0.52	0.20	0.10
Compensated dollar		0.07	0.05	0.02	0.01
Price path $(v_\pi, v_y, v_p, v_{p1}) = (0, 0, 0.2, 0)$		0.07	0.03	0.02	0.01

## Fisher's Compensated Dollar

Fisher (1913) proposed the compensated dollar scheme in which the central bank would construct and target a price index for the basket of non-gold goods. Although this plan was never implemented, it is interesting because it is a forerunner of modern proposals to target the price level and actual inflation-targeting regimes. In this simple case with only gold coins circulating as money, the model is the same as the gold standard except that the government manages the mint price so that the price of the non-gold good is stabilized at its steady-state level. Thus, there will still be some variation in the aggregate price level that includes the gold price.

Figure 2: Gold Standard Vs. Compensated Dollar



Responses are quarterly. The shocks are one-standard deviation calibrated to 2 percent for the gold technology shock and 1 percent for the non-gold goods technology shock. The gold standard responses are shown with a dashed line and the compensated dollar responses are shown with a solid line.

The significant difference between the economies under these two alternative regimes is in the behavior of relative prices. The compensated dollar standard requires the mint price to be adjusted in a way that causes a larger change in the

relative price of gold in response to all shocks. The top two panels in Figure 2 show the relative gold price responses to a gold technology shock (left panel) and the non-gold goods technology shock (right panel). Under the gold standard, the gold price is fixed and the price level rises about 1 percent in response to a 2 percent gold shock (causing the relative price of gold to fall). Under Fisher's plan, the government must lower the mint price by more than 1.5 percent to prevent the goods price from rising. The top right panel shows the response of the relative gold price to a shock to technology in the goods sector. Under the gold standard, price level falls about 0.7 percent, raising the relative price of gold. Under Fisher's plan, the government raises the mint price by more 1 percent to prevent the goods price from falling. The output responses to shocks are very similar to those under the gold standard and are not shown here.

The lower panels in Figure 2 show how the money supply differs under the two regimes in response to both shocks. Under the gold standard a gold shock causes a rise in nominal consumption expenditures that leads to a rise in the demand for money balances. This effect dominates the relative price effect that induces an increased use of gold capital in the gold sector. Under the compensated dollar, nominal consumption spending is relatively unchanged. The lower relative price of gold causes it to be used more intensely in gold production with a negative effect on the level of money balances (see the lower left panel).

Under the gold standard, a shock to technology in the goods sector causes the goods price to fall, leading to a decline in the demand for money balances. Under Fisher's plan, the government raises the mint price by more than 1 percent. The increase in nominal consumption spending is all due to higher real spending, inducing a persistent rise in money balances above the steady state (see lower right panel).

Table 3, row 3 reports the uncertainty about average inflation with the compensated dollar. The standard deviation of the average inflation rate is less than 0.1 percent at all horizons. The price of the non-gold good is stabilized exactly, so that the remaining uncertainty in the inflation rate is coming from the price of gold. The implied uncertainty about the inflation rate is an order of magnitude smaller with the compensated dollar regime than is under the gold standard.

## **VI. PAPER MONEY AND INTEREST RATE RULES**

Conceptually, one of the important criticisms of the gold standard was that gold is a real resource with uses other than money. If the government issues paper certificates that are claims to gold, and the policy is credible, replacing costly gold with paper money should release real gold resources and result in higher welfare. In Sweden the government and the banking system operated with convertible

paper money and low gold reserves.<sup>9</sup> As long as people were willing to hold the paper as if it were gold, there was little need to hold large gold reserves. With our assumption of perfect credibility, all money is paper and all gold is consumed or used as capital, so consumption and utility are higher than they are when gold coins are used as money.<sup>10</sup>

Under a gold standard with paper money, the central bank uses an interest rate rule to maintain the gold price close to par. The interest rate rule is defined by the set of policy parameters:  $(\nu_\pi, \nu_y, \nu_p, \nu_{pl}) = (0, 0, 0, 0.25)$ . The parameter  $\nu_{pl}$  was calibrated to match the term structure of volatility of the average inflation rate under the gold standard (row 1 of Table 3). The first two lines of Table 2 show that the short-run behavior of output and the price level are quite similar for the pure gold standard and the gold standard with fiat money. With this calibration, the gold price rarely strays outside of a range of plus or minus 0.6 percent. Officer (1986) estimates that the gold points averaged 0.64 percent of parity between 1890 and 1908. Results by Canjels et al. (2004) suggest that this may exaggerate the actual movements in the gold price relative to history. Using a recently developed daily time series on New York dollar-sterling exchange rates, they estimate that the gold points declined gradually from about 0.3 or 0.4 percent of parity in 1879 to about half of that in 1913.

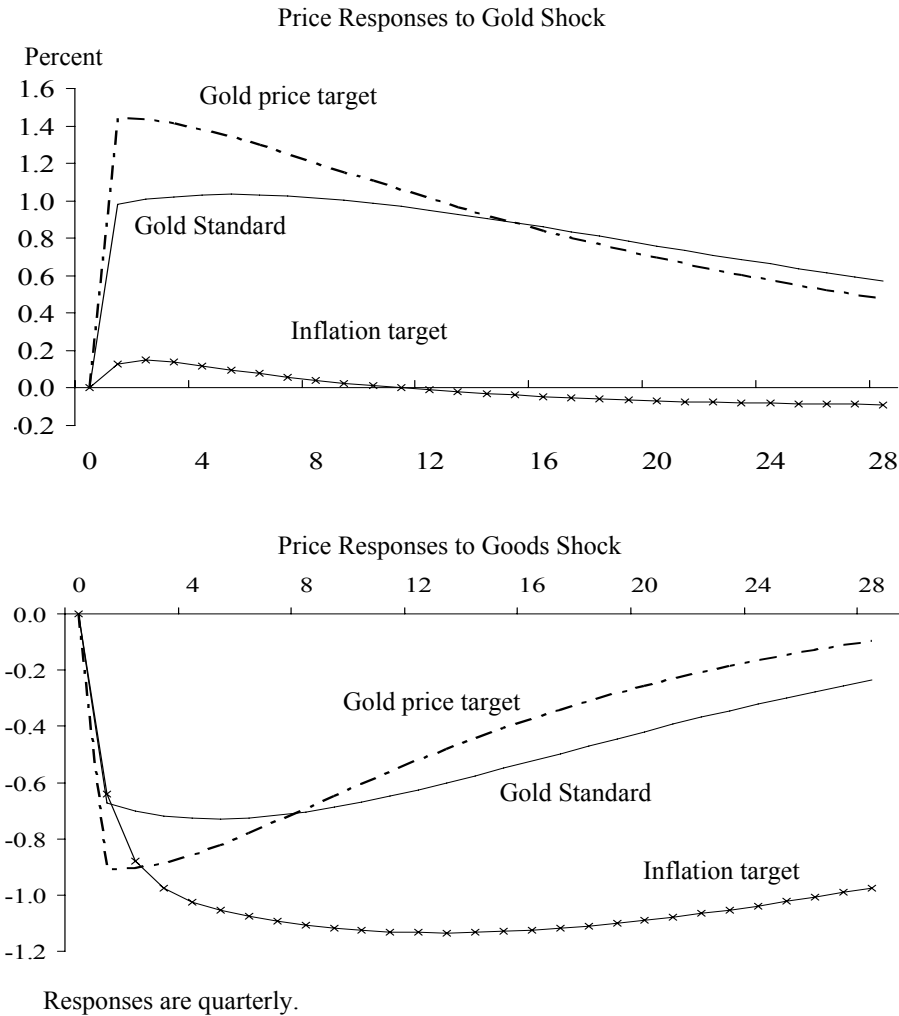
Adding paper claims to gold in a credible regime allows households to use more of the gold as capital and consumption, raising output and utility. The dynamics of the price level also change, but not much. Following a gold technology shock, the price of other goods rises and the price of gold falls slightly. With this calibration, a gold shock causes the aggregate price level to jump about 1.4 percent (see Figure 3). The real rate rises with the increase in the marginal return to capital. The policy rule requires the nominal rate to fall below the steady-state rate. The equilibrium path for the price level requires a long period with enough deflation to produce the spread between the real rate and the nominal rate implied by the rule. This is achieved by the unexpected rise in the price level associated with the shock and the subsequent gradual return to the steady state. The size of the government's reaction determines how much the price level will jump. A more aggressive response—a larger parameter—causes a larger initial jump in the price of other goods and a higher average deflation during the transition back to the steady state.

---

<sup>9</sup> See Jonung (1984).

<sup>10</sup> Again, this assumes perfect credibility. Friedman (1986) argues that there is a demand of gold as a monetary asset when there is less than perfect credibility in a regime with irredeemable paper money.

Figure 3: Aggregate Price Dynamics



Following a shock to goods technology, the price of gold tends to rise and the price of other goods falls. As in the case of the gold shock, the real rate rises. Now, the nominal rate must also rise to prevent the gold price from rising. An equilibrium response with the gold price policy rule requires the price level to fall enough in the initial period so that the subsequent inflation is consistent with the paths for nominal and real interest rates. With both shocks, the gold price target exacerbates the fluctuations in the goods price relative to those expected under the gold standard.

## Inflation Targeting

In this regime the central bank uses the interest rate rule to target the aggregate inflation rate. Here, we ignore the effect of policy-induced shocks and, as before, we assume complete credibility for the policy.<sup>11</sup> The pure inflation targeting rule is given by  $(\nu_\pi, \nu_y, \nu_p, \nu_{pl}) = (1.5, 0, 0, 0)$ . The aggregate price level response to shocks with an inflation target is also shown in Figure 3. The central bank sets the interest rate target equal to its steady-state value plus 1.5 times the deviation of aggregate price inflation from the steady state. We chose the value reported by Taylor (1993) as “working well” in the post-1980 U.S. economy. A gold technology shock causes the real rate and the aggregate price level to rise. Here, however, gold is just another commodity. The inflation rule eliminates the need for a jump in the price level and, thus, the inflation response remains small. Thus, as we found for the compensated dollar, inflation targeting will eliminate the price fluctuations induced by shocks to the gold sector. However, an inflation target does not help much when there are shocks to the goods sector. The price response is damped slightly in the short-run, but the price effects go on much longer because there is no direct mechanism for correcting for the deviation of the price level from the steady state.

## Inflation Targeting and Inflation Uncertainty

Table 4 reports the standard deviation of the average inflation rate for alternative interest rate rules. With pure inflation targeting (and no policy-induced errors), there is little uncertainty about inflation at any horizon. The situation changes, however, if the central bank reacts to output. Increasing the weight on output  $\nu_y$  from 0 to 0.0125 raises the standard deviation of the 30-year average inflation rate from 0.26 to 0.52 percent. Increasing the weight again to 0.05 almost triples the standard deviation to 1.43 percent. If we increase the weight on output to the value suggested by Taylor (1993),  $\nu_y = 0.125$ , the standard deviation jumps to 4.28 percent. This is large relative to actual experience, even during the high inflation period of the 1970s. To adequately replicate that experience, we can assume a lower weight on real output or add some concern about past deviations of inflation from target.<sup>12</sup>

---

<sup>11</sup> See Erceg and Levin (2003) for an analysis with imperfect credibility. See Ireland (2007) and Gavin, Keen and Pakko (2006) for an analysis of policy-induced errors.

<sup>12</sup> An alternative way to show concern about past deviations of inflation from target is to have a target average inflation over several period, see Nesson and Vestin (2005).



Table 4: Term Structure of Inflation Uncertainty with Inflation Targeting Rules:  
Standard Deviation of Average Inflation from Steady State (Percent)

Interest rate rules of the form $(\nu_\pi, \nu_y, \nu_p, \nu_{pl}) = (1.5, \nu_y, 0, 0)$				
$\nu_y = 0$	0.07	0.17	0.17	0.26
$\nu_y = 0.0125$	0.06	0.18	0.42	0.52
$\nu_y = 0.05$	0.23	0.91	1.41	1.43
Taylor rule ( $\nu_y = 0.125$ )	0.78	3.17	4.44	4.28

### Price Path Targeting and Inflation Uncertainty

Looking back to the fourth row in Table 3 we see that a pure price path target can come close to mimicking Fisher's compensated dollar in our model if the central bank targets a path for the aggregate price level with  $\nu_p = 0.2$ . As with the compensated dollar, the price level is anchored in the long run, and the uncertainty at all horizons is an order of magnitude smaller than with an inflation target or with the gold standard.

Table 5 shows results in which we start with the Taylor parameter of 0.125 on output, but also include a response to the deviation of the price level from the steady state path. Just adding a small weight (0.0125) reduces the standard deviation of the 30-year inflation rate to 1.06 percent. Increasing the weight on the price level deviation reduces the uncertainty across all horizons. If we set the weight on the price level equal to the weight on output (0.125), then the term structure of uncertainty lies within the envelope that we found for the gold standard.

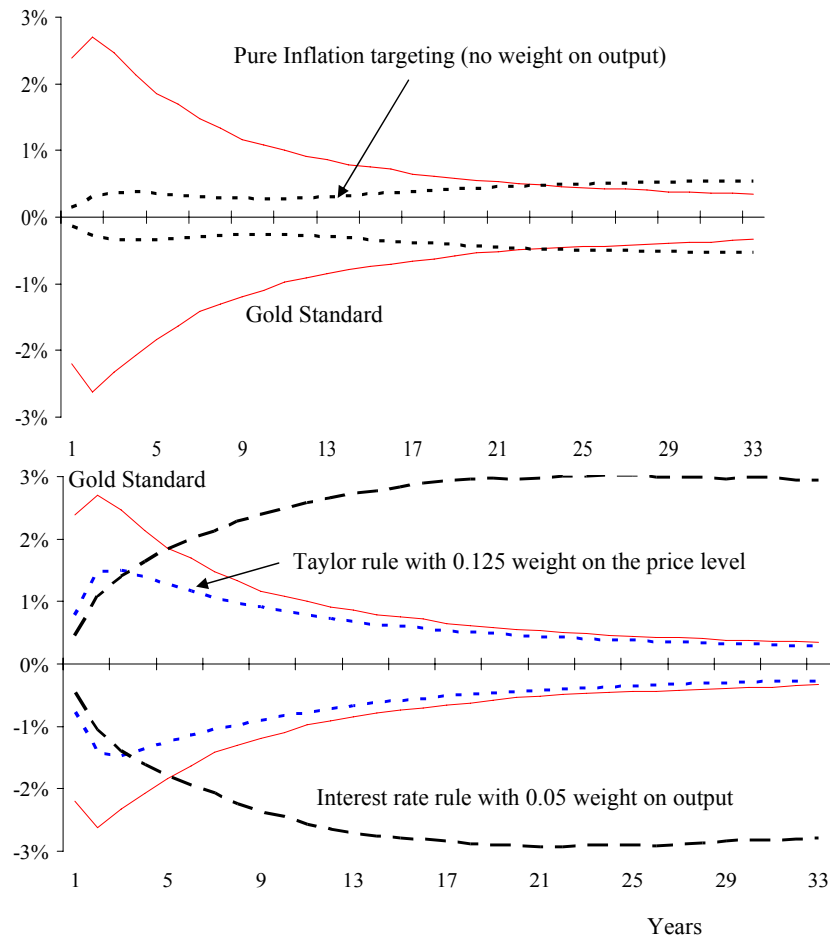
Table 5: Term Structure of Inflation Uncertainty with the Taylor Rule and Weight on a Price Path: Standard Deviation of Average Inflation from Steady State (Percent)

Taylor rules of the form $(\nu_\pi, \nu_y, \nu_p, \nu_{pl}) = (1.5, 0.125, \nu_p, 0)$				
$\nu_p = 0.0125$	0.67	2.19	1.86	1.06
$\nu_p = 0.05$	0.74	1.67	0.83	0.43
$\nu_y = 0.125$	0.39	0.63	0.30	0.15

## VII. SUMMARY OF MAIN RESULTS AND CONCLUSION

The main results of this paper are illustrated nicely in Figure 4 where we report the results for every horizon from 1 to 33 years for four of the policy regimes—the gold standard, a pure inflation target, an inflation target with a small weight on output, and a Taylor rule that also includes a target for a price path.

Figure 4: Long-Run Inflation Uncertainty—Alternative Regimes



The values in the figure 95 percent of the outcomes for deviation of the inflation rate the steady state computed using 10000 replications of the relevant model.

The top panel of Figure 4 compares the gold standard with a pure inflation target. With our baseline calibration, 95 percent confidence intervals for the inflation rate under the gold standard are rather large (2 to 3 percent) for short

horizons, but stabilize to plus and minus 3/4 percent at a 15-year horizon and decline to less than plus and minus 1/2 percent at 30-year horizons and longer. A credible pure inflation target would do much better, keeping inflation uncertainty at or less than plus or minus 1/2 percent for up to 30 years. As McCallum (1999) argued, a pure inflation target (one that does not include a reaction to real variables) does not involve much price level uncertainty even over horizons as long as 20 or 30 years. But the long-run uncertainty rises rapidly as the central bank begins to show some concern for real output.

The bottom panel Figure 4 shows what happens if the central bank puts a small weight on output.<sup>13</sup> Here, inflation forecast uncertainty is quite low at a 1-year horizon. It grows to match the uncertainty under the gold standard at a 5-year horizon and grows to plus a minus 3 percent at horizons of 20 years and longer.

In the bottom panel of Figure 4 and in Table 4 we also report the results of a central bank that puts substantial weight on output (0.125 as in the Taylor rule), but also puts weight on the deviation of price level from a steady state path. With our policy vector  $(\nu_\pi, \nu_y, \nu_p, \nu_{pl}) = (1.5, 0.125, 0.125, 0)$ , the short-run inflation uncertainty is half that associated with the Taylor rule and the long-run uncertainty is as small as with the gold standard (at least an order of magnitude smaller than with a rule that ignores the price level).

The advantage of adhering to the gold standard is that it provides a market-driven mechanism to ensure long-run price stability. The disadvantage is that it involves significant resource costs and makes aggregate price level volatility depend on real shocks. Nevertheless, the gold standard has long been viewed as superior to an inconvertible fiat regime in providing for price stability. But a fiat regime based on a credible nominal anchor provides the price stability benefits of the gold standard with neither the resource costs nor the short-run variability associated with the gold standard.

Our computational experiments corroborate much of the accepted wisdom about the gold standard and provide insights about modern inflation targeting. As Irving Fisher argued, we find that if a central bank wants price stability for the short-term, then stabilizing a broad price index clearly dominates the classic gold standard. We find that adding some weight to a path for the price level gives the central bank the flexibility to respond to real output without sacrificing its goal of price stability. The intuition is simply that the target for the price path anchors long-term inflation expectations.

---

<sup>13</sup> Here a 0.05 reaction to the output level for our quarterly specification of inflation and interest rates is equivalent to a Taylor rule with a coefficient of 0.2. The Taylor rule is generally written with the interest and inflation at annual rates.

## REFERENCES

- Atack, Jeremy, and Fred Bateman. "How Long Was the Workday in 1880?" *Journal of Economic History*, March 1992, **52**, 129-160.
- Backus, David K. and Patrick J. Kehoe. "International Evidence on the Historical Properties of Business Cycles." *American Economic Review*, September 1992, **82**(4), 864-88.
- Barro, Robert J. "Money and the Price Level Under the Gold Standard." *Economic Journal*, 1979, **89**, 12-33.
- Bergman, U. Michael, Michael D. Bordo, and Lars Jonung. "Historical Evidence on Business Cycles: The International Experience," in *Beyond Shocks: What Causes Business Cycles?* Federal Reserve Bank of Boston, Conference Series No. 42, 1998, 65-113.
- Bordo, Michael D. "The Classical Gold Standard: Some Lessons for Today." Federal Reserve Bank of St. Louis *Review*, May 1981, **63**, 2-17.
- Bordo, Michael D., and Lars Jonung. "A Return to the Convertibility Principle? Monetary and Fiscal Regimes in Historical Perspective," in Axel Leijonhuvud (ed.) *Monetary Theory as a Basis for Monetary Policy*. MacMillan, London, 2001.
- Bordo, Michael D., and Finn E. Kydland. "The Gold Standard as a Monetary Rule." *Explorations in Economic History*, 1995, **32**, 423-464.
- Bureau of Labor Statistics. *Wholesale Prices: 1890 to 1919*, Bulletin of the United States Bureau of Labor Statistics No. 269. Washington: Government Printing Office, July 1920.
- Canjels, Eugene, Gauri Prakash-Canjels, and Alan M. Taylor. "Measuring Market Integration: Foreign Exchange Arbitrage and the Gold Standard, 1979-1913." *Review of Economics and Statistics*, November 2004, **86**, 868-882.
- Dickey, David A. and Wayne A. Fuller. "Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root." *Econometrica*, July 1981, **49**, 1057-1072.

- Dittmar, Robert, William T. Gavin, and Finn E. Kydland. "Inflation Persistence and Flexible Prices." *International Economic Review*, February 2005, **46**, 245-261.
- Eichengreen, Barry. *Golden Fetters: The Gold Standard and the Great Depression, 1919-1939*. New York: Oxford University Press, 1992.
- Erceg, Christopher J., and Andrew T. Levin. "Imperfect Credibility and Inflation Persistence." *Journal of Monetary Economics*, May 2003, **50**, 915-44.
- Fisher, Irving. *Stable Money: A History of the Movement*. London: Adelphi Press, 1934.
- \_\_\_\_\_. "A Compensated Dollar." *Quarterly Journal of Economics*, February 1913, **27**, 213-235.
- Friedman, Milton. "The Resource Cost of Irredeemable Paper Money." *Journal of Political Economy*, 1986, **94**, 642-647.
- \_\_\_\_\_. *A Program for Monetary Stability*. New York: Fordham University Press, 1960.
- \_\_\_\_\_. "Commodity-Reserve Currency." *Journal of Political Economy*, June 1951, **59**, 203-32.
- Friedman, Milton and Anna Schwartz. *A Monetary History of the United States: 1867-1960*, Princeton University Press, Princeton, 1963.
- Fujiki, Hiroshi. "A Model of the Federal Reserve Act under the International Gold Standard System." *Journal of Monetary Economics*, 2003, **50**, 1333-50.
- Fuller, Wayne. *Introduction to Statistical Time Series*, John Wiley & Sons, New York, 1976.
- Gavin, William T., Benjamin D. Keen and Michael R. Pakko. "Inflation Risk and Optimal Monetary Policy." Federal Reserve Bank of St. Louis Working Paper 2006-054A, September 2006.
- Goodfriend, Marvin. "Central Banking under the Gold Standard." *Carnegie Rochester Conference Series on Public Policy*, Spring 1988, **29**, 85-124.

- Huffman, Gregory W. and Mark A. Wynne. "The Role of Intratemporal Adjustment Costs in a Multisector Economy." *Journal of Monetary Economics*, 1999, **43**, 317–50.
- Ireland, Peter N. "Changes in the Federal Reserve's Inflation Target: Causes and Consequences." Manuscript Boston College, January 2007, forthcoming *Journal of Money, Credit, and Banking*.
- Jastram, Roy W. *The Golden Constant: The English and American Experience 1560 -1976*, John Wiley & Sons, New York, 1977.
- Jonung, Lars. "Swedish Experience under the Classical Gold Standard, 1873-1914," in *A Retrospective on the Classical Gold Standard, 1821—1931*, Bordo, Michael D., and Anna J. Schwartz eds., Chicago: The University of Chicago Press, 1984, 361-399.
- King Robert G. and Mark W. Watson. "The Solution of Singular Linear Difference Systems Under Rational Expectations." *International Economic Review*, November 1998, **39**, 1015-26.
- Klein, Benjamin. "Our New Monetary Standard: The Measurement and Effects of Price Uncertainty, 1880-1973." *Economic Inquiry*, December 1975, **13**, 461-84.
- Kydland, Finn E. "Monetary Policy in Models with Capital," in *Dynamic Policy Games*, van der Ploeg, F. and A. J. de Zeeuw eds., Amsterdam: Elsevier Science Publishers B.V. (North-Holland), 1989.
- Long, John B. Jr., and Chales I. Plosser. "Real Business Cycles." *Journal of Political Economy*, February 1983, **91**, 39-69.
- McCallum, Bennett T. "Issues in the Design of Monetary Policy Rules." *Handbook of Macroeconomics* **1C**, Amsterdam: Elsevier Science, North-Holland, 1999, 1483-1530,
- Meltzer, Allan H., and Saranna Robinson. "Stability under the Gold Standard in Practice," in *Money, History, and International Finance: Essays in Honor of Anna J. Schwartz*, University of Chicago Press: Chicago, 1989, 163-95.

- Murphy, Kevin M., Andrei Shleifer, and Robert Vishny. "Building Blocks of Market Clearing Business Cycle Models," in *NBER Macroeconomics Annual 1989*, Olivier J. Blanchard and Stanley Fischer eds., Cambridge: MIT Press, 1989, 247-87.
- Nesson, Marianne, and David Vestin. "Average Inflation Targeting." *Journal of Money, Credit, and Banking*, October 2005, **37**, 837-863.
- Officer, Lawrence H. "The Efficiency of the Dollar-Sterling Gold Standard, 1890-1908." *Journal of Political Economy*, October 1986, **94**, 1039-1073.
- Report to the Congress of the Commission on the Role of Gold in the Domestic and International Monetary Systems, March 1982.
- Sargent, Thomas J. and Neil Wallace. "A Model of Commodity Money." *Journal of Monetary Economics*, 1983, **12**, 163-87.
- Stock, James H. "Confidence Intervals for the Largest Autoregressive Root in U.S. Macroeconomic Time Series." *Journal of Monetary Economics*, 1991, **28**, 435-59.
- Taylor, John B. "Discretion versus Policy Rules in Practice." *Carnegie-Rochester Conference Series on Public Policy*, 1993, **39**, pp. 195-214.